DESIGNING AIRFIELD PAVEMENT FOR HEAVY JUMBO JETS

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PRESENTED FOR THE
2004 FAA WORLDWIDE AIRPORT TECHNOLOGY TRANSFER CONFERENCE
Atlantic City, New Jersey, USA

April 2004

ABSTRACT

In response to a new type of constraint caused by the landing gear of heavy jumbo jets (Airbus A340-600, A380, Boeing B777), and, in particular, to help adapt existing airport pavement to this type of traffic, several experiments have been undertaken involving the application of high performance asphalt mix. These experiments were designed to find ways to optimize the nature and thickness of materials as well as the time required to apply them, while ensuring best possible safety and comfort.

The Toulouse Airport and the Paris Airport Authorities – where the first Airbus A380 is scheduled to land – were naturally the first to participate in these tests.

This paper will describe two experiments carried out in 2001: the first covers the reinforcement of flexible pavement at the Toulouse Airport and the second describes the reinforcement of cement concrete slab pavement at the Paris - Charles de Gaulle Airport. The latter will also enable us to compare the real level of stress and strain caused by the landing gear by observing, in situ, the damage caused by the highly frequent airplane traffic: Airbus A320, A330, A340 and Boeing B747, B777, McDonnell MD11, etc.

In terms of the pavement's structural design, the ACN-PCN methods cannot be used, given the traffic forecast for planes such as the Boeing B777 and Airbus A380, which weigh as much as 600 tons at take-off. The bearing capacity of the existing pavement and the thickness of the reinforcement were verified using an original method involving the concept of admissible thresholds. This is a rational method that was developed and has been used for the past ten years in France, based on a numerical calculation of finite elements, using "CESAR-3D" software, designed by the French "Laboratoire Central des Ponts et Chaussées".

In addition to the optimization of technical and economic issues, the experiments also studied the choices of techniques and non-toxic, non-health hazardous recyclable materials, in compliance with the principles of the sustainable development.

BACKGROUND

In order to cope with the continuous rise in demand, the capacity levels of airports and aircraft have greatly increased over the last two decades. Airport pavement is thus subject to heavier aircraft and a greater number of landings and take-offs, which of course accelerates fatigue and damages the pavement in situ.

This phenomenon has been observed in all international and regional airports.

If we take extremely heavy aircraft into account, such as the Airbus A380 and the lengthened versions of Boeing, estimates show that a significant number of airports need to extend, reinforce and even rebuild the runway pavement to adapt to this new type of heavy traffic.

Today, airport managers are looking for economical, reliable solutions to reinforce runway pavement as quickly as possible.

The entire profession recognizes that the current CBR-based design methods are no longer sufficient.

Indeed, one of the main problems that researchers encounter with CBR methods is that they do not take changes in materials and mechanical characteristics into account, which would allow for major savings in terms of raw materials and cost. Further proof of the insufficiency of CBR methods comes from the fact that they were designed for single-wheel landing gear, and can not be adapted to the new types of multi-wheel techniques.

Airport pavement designers are looking for a universal design method that offers solutions for new pavement as well as reinforcement of all types of structure (rigid, flexible, composite), and all types of traffic and landing gear, for sub grade and existing pavement, and any type of climate.

THE “ELSA” METHOD

The ELSA concept (Acceptable Limits Service) was developed in the late 1980s, following the economic problems and budgetary restrictions that France. The goal was to propose reliable solutions, based on the client’s required level of service.

This rational design method combines recent three-dimensional finite elements methods and rheological laws of materials behavior.

The design principle consists in determining the maximum amount of strain and stress in the layers at the different stages of the structure’s evolution, and then comparing them with the acceptable limits materials constitutive of the structure. The design is optimal when the strains or stresses in each layer, are equal to acceptable fatigue thresholds.

The acceptable thresholds are particularly related to the level of pavement degradation including permanent cracks, permanent deformations, differential beats, etc.

The stresses and strains are calculated using the “CESAR-3D” finite element software, created by the “French Laboratoire Central des Ponts et Chaussées” (French Central laboratory of Road and Bridges). This numerical calculation model makes it possible to integrate all types of materials behavior laws, in linear elasticity and elastoplasticity. The interface between the layers can be full friction or no friction, and even a certain degree of friction. The structure is modeled according its real dimensions, by taking the edges, corners and cracks in the layers into account. The loads are represented by the real form and the real pressure applied on the load zone.

Our “LIM” software allows to determine acceptable limits, according to the constitutive laws and mechanical properties of the materials, in addition to the real traffic of each aircraft.

Basis of the Pavement Design Method

The method is based on elastic theory of pavement response to traffic stresses and results of reported filed and laboratory investigations in witch material properties and behaviour have been characterized.

The major steps in “ELSA” are:

1. Make a preliminary design of the structure be reference to comparable situations.

2. Structure modeling: Our experience shows that the use of an elastic model allows with a good satisfaction the pavement modeling under dynamic loading. Indeed, the precision brought by the use of visco-elastoplastic behavior laws (much more complex) is negligible sight the great difficulty in obtaining precise data input such characteristics representative of materials, traffic, etc. Nevertheless, in static loading, the behavior of the bituminous mix is not elastic.

3. Structural calculation: The stresses and strains are calculated for the pavement structure outlined in step 1, under the reference traffic load. The criteria chosen for the designing are: horizontal tensile strain (ε_t) for bituminous layers, horizontal tensile stress (σ_t) for layers with hydraulic binders and vertical tensile strain (ε_z) for subgrade. The critical locations in a pavement are shown diagrammatically in Figure 1.

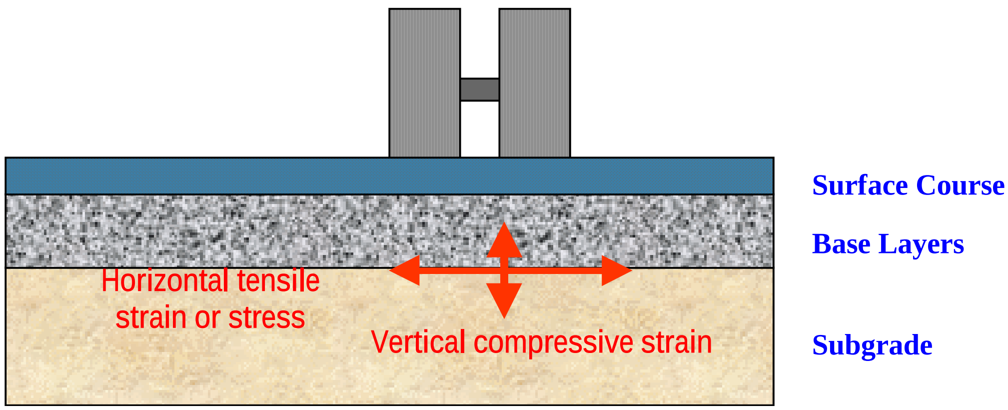

Figure 1. Critical stresses - strains and locations in pavement layers.

4. Determination of fatigue limit values: These limit values are determined according to: the cumulated traffic over the calculation period, the material fatigue strength characteristics, thermal effects, accepted service level, data obtained by observing the beaviour of other pavements of the same type, etc.

5. Structural verification: The verification is done comparing the maximal stresses and strains calculated in step 3 to the fatigue limit values calculated in step 4.

Factors Involved in Pavement Design

The design method includes the following factors:

<u>Aircraft traffic</u>

It is necessary to gather information known about the types of aircraft, landing gear, load and pressure by wheel, movements of each type of aircraft, etc.

Design should be based upon the Critical Aircraft which is defined as the aircraft whose landing gear load and number of repetitions leads to the most pavement damage. The entire traffic should be expressed as a number of passes of the critical aircraft (or aircraft of reference).

The relations of equivalence between different landing gears (the aggressiveness) are equivalences of unit damage.

The aggressiveness of an aircraft (A) is estimated according the fatigue damage caused to the pavement:

$A = K \cdot \left(\frac{\varepsilon}{\varepsilon_0} \right)^{\alpha}$ for flexible pavement, and $A = K \cdot \left(\frac{\sigma}{\sigma_0} \right)^{\alpha}$ for rigid and semi-rigid pavement.

Factor K is used to take into account the landing gear type. K and α depend of the nature of material and the pavement structure.

The traffic factor is the average aggressiveness of the aircraft composing the total traffic.

<u>Calculation risk and service level</u>

The random nature of the various factors has significant effect on the durability of the pavement over time. So the structure designing study must be envisaged in probabilistic terms. The risk calculation is the probability of failure of the pavement at the end of calculation period.

<u>Pavement foundation (subgrade)</u>

The bearing pressure of the ground soil or the subgrade expressed in elastic modulus (E). CBR measurements are difficult and often vague.

<u>Environment (climatic data)</u>

The climatic conditions affect the choice of the nature of bituminous binders. The temperature and the severity of frost periods are used in the design calculation.

<u>Pavement materials</u>

Pavement materials and their characteristics can be classified essentially into three categories:

1. Untreated aggregates: no intrinsic characteristics, but an elastic modulus (E) that depends of under-layer modulus and Poisson's Ratio.

2. Bituminous materials: visco-thermoelastic modulus, fatigue behavior (bending fatigue test in figure 2), and Poisson's Ratio.

3. Materials treated with hydraulic binders: elastic modulus, fatigue behavior (bending or simple tensile strength) and Poisson's Ratio.

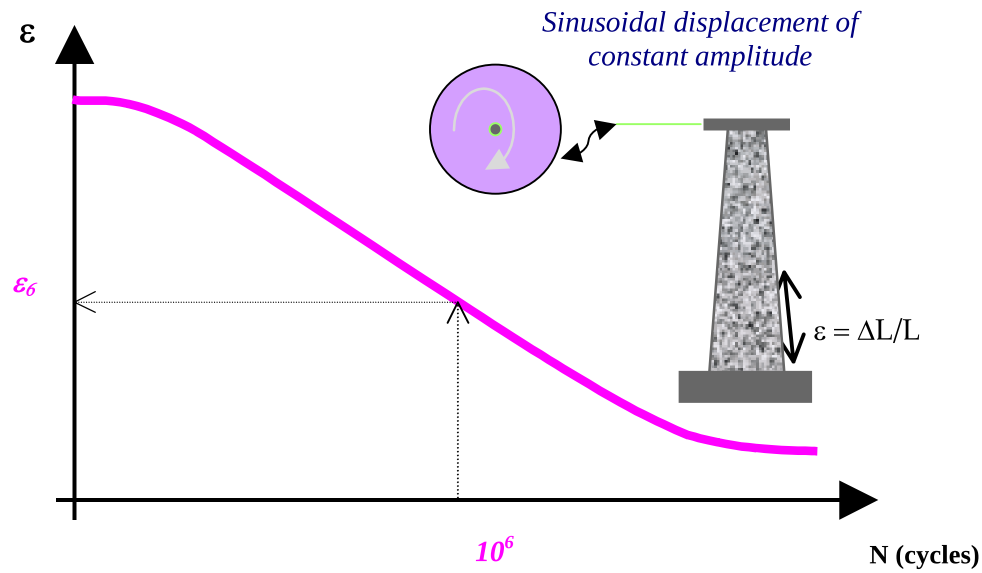

Figure 2. Fatigue Behavior Using Bending Fatigue Test (French Standard NF P 98 261-1).

Table 1.
Indicative Mechanical Characteristics of Bituminous Materials.

Material	*E* (15°C, 10Hz) (MPa)	ε_6(10°C, 25Hz) (10^{-6})[a]
Airfield Asphalt Concrete (AAC)	5400	100
High Modulus Asphalt Concrete (HMAC)	12000	100
Road Base Asphalt Concrete (RBAC)	9300	90
High Modulus Road Base Asphalt Concrete (HMRBAC)	14000	130
Multicol Asphalt Concrete (Multicol AC)	14000	140

[a]ε_6= Fatigue tensile strain value (at 10°C and 25 Hz) for 1 million cycles, expressed in μ deformation

Table 2.
Indicative Mechanical Characteristics of Materials Treated with Hydraulic Binders

Material	E (MPa)	Flexure Tensile Strength σ (MPa)
Cement Bound Materials (CBM)	25000	1.5
Cement Concrete (CC)	35000	4.7

Adjustment between computation model results and observed pavement behavior

The monitoring of a significant number of experimental pavements sites and the rational analysis of the damage that had occurred, allowed the validation and the adjustment of the design method by back-calculation analysis. The following pavement sections are located in very different geographical areas, with a wide range of climate, materials, etc.

EXPERIMENTAL PAVEMENTS

The Toulouse Airport and the Airports of Paris (where the first A380 Airbus is scheduled to land) were naturally the first to participate in these tests.

We describe in this paper two experiments carried out in 2001: the first covers the reinforcement of flexible pavement at the Toulouse Airport in order to validate the ELSA design method for large and heavy aircraft. The second covers the reinforcement of cement concrete slabs pavement at the Charles de Gaulle airport in Paris. The latter will also allow us to compare the real level of aggressiveness of the landing gear, by observing, in-situ, the damage caused by extremely frequent airplane passages of major aircraft such as Airbus A320, A330, A340, Boeing B747, B777, McDonnell Douglas MD11, etc.

The reinforcement technique is identical in both cases. It consists of combining a layer of asphalt mix with high performances Multicol asphalt concrete.

Multicol is a composite hot asphalt mix. It offers all of the advantages of the bitumen polymer-modified asphalt binders, such as high fatigue strength and resistance to cracking at low temperatures. It is also exceptionally resistant to punching and rutting, thanks to a tailor-made design mix and a special selection of additive agents. In addition to its mechanical characteristics, Multicol is highly resistant to the chemical agents that attack pavement such as fuel, deicing salts, jack oil, etc.

Multicol's mechanical performances are illustrated in table 3.

Table 3.
Typical values obtained on Multicol-Asphalt Concrete, Airfield Asphalt Concrete and High Modulus Asphalt Concrete.

Tests	Multicol-AC	AAC	HMAC
Fatigue resistance - NF P 98-261-1 at (10 °C, 25 Hz) (µ strain)	> 150	100	100
Complex modulus - NF P 98-260-2 at (15 °C, 10 Hz) (MPa)	14000	5400	12000
Resistance to rutting – NF P 98-253-1 to 60 °C and 0.6 MPa, after 100 000 cycles (in %)	2.2	10	5
Anti-K resistance - NF P 98-251-1 (r/R after 7 days in the kerosene)	0.66	0.05	0.06

The Multicol asphalt mix was tested for resistance to airplane fuel. The value obtained makes it possible to classify it in "high class," i.e., behaving well when in contact with aggressive hydrocarbon solvents.

Experiment at the Toulouse Airport

In August 2001, the taxiway of Toulouse Airport was the object of comparative experimental boards of pavement reinforcement, of which one was carried out in Multicol.

The goal of this experiment was to verify the pavement behavior with respect to fatigue, rutting, punching, kerosene resistance, thermal cracking, etc.

The main design data relating to large super jumbos are the following:

- weights of 395 tons for the Boeing 747-400 up to 560 tons for the A380-800 Airbus,
- weights of bogies: 108 tons for the A340-600 Airbus up to 170 tons for the A380 Airbus,
- high tyre contact pressure up, to 1.8 MPa.

Reinforcement Solution

The reinforcement solution consists in the replacing the old damaged AAC wearing course with Multicol-AC, in layers ranging in thickness from 60 to 80 mm.

The asphalt mix was made with 0/14 aggregates, polymer modified asphalt binder and special additives.

The existing pavement was prepared (planing - reshaping) and was covered with a polymer-asphalt emulsion tack coat before the application of Multicol.

The experimental section is 100 meters long and half of the width of the Taxiway. The other half was covered with a traditional 0/14 AAC. The goal was to compare the behavior of both structures.

The final critical structure after reinforcement is as shown in Figure 3.

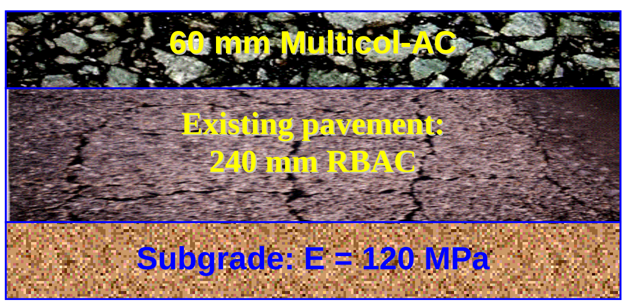

Figure 3. Final Critical Structure After Reinforcement.

In addition to the loading of static tests, the existing pavement had undergone, during experiment PEP (Airbus A380 Pavement Experimental Program), 5000 passages of simulator. This represented medium to heavy traffic of Boeing B777s, B747-400s, and A380 Airbus planes on this type of airfield pavement.

The pavement design was controlled using the ELSA method.

The existing pavement reinforced with 60 mm of Multicol-AC makes it possible to clearly improve the design life and the structure behavior under the traffic of B747-400 and A380 (these planes are considered to be the most aggressive regarding pavement damage). Figures 4 and 5 show results of modeling with finite elements using Cesar-3d.

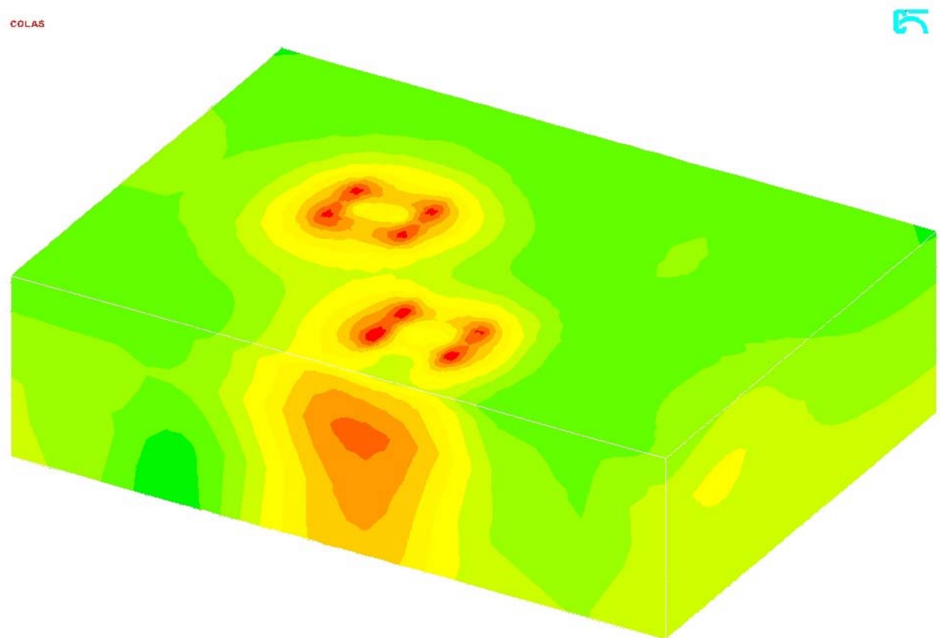

Figure 4. Vertical strains on the subgrade under B747-400 landing gear.

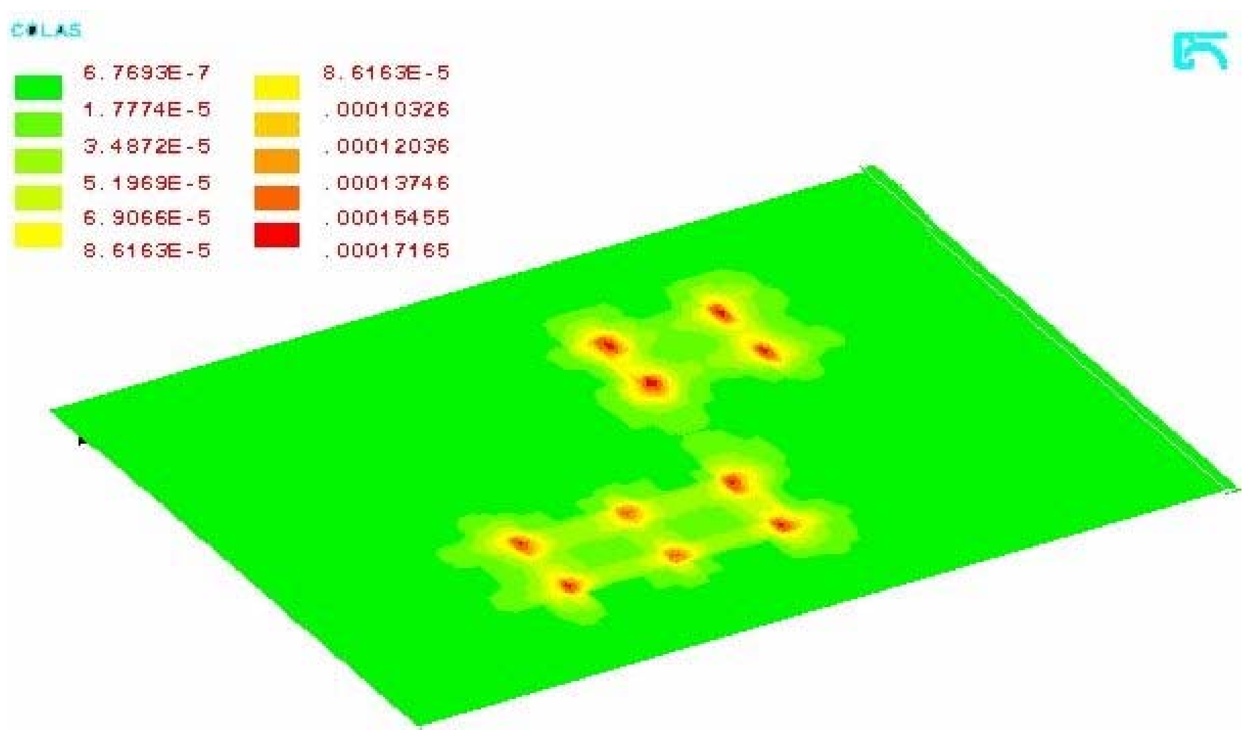

Figure 5. Horizontal tensile strains in the pavement under A380 landing gear.

Acceptable aircraft traffic according to the choice of the wearing course (regular AAC or Multicol-AC), combined with the risk of damage, are illustrated in Figure 6.

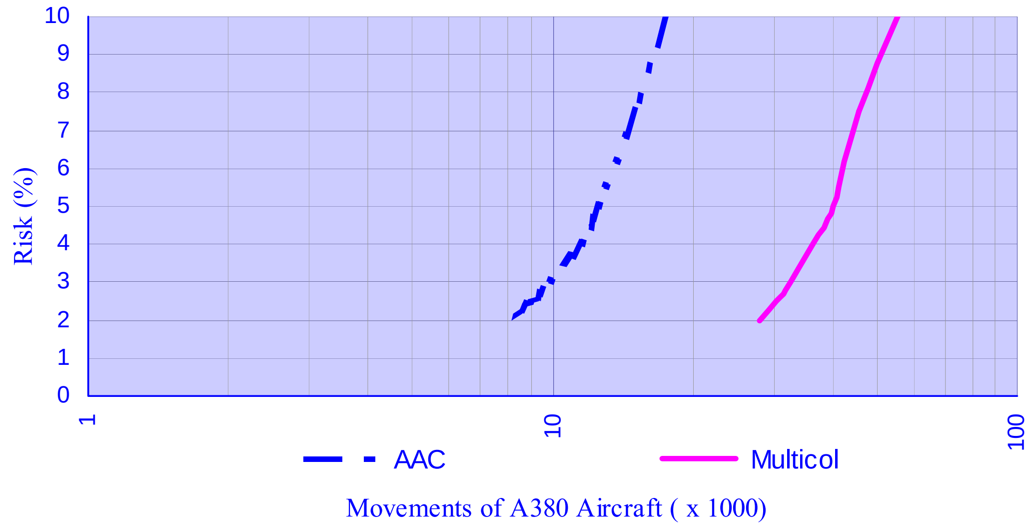

Figure 6. Acceptable aircraft traffic according to type of wearing course.

If we consider a 2% calculation risk (i.e. damage at the end of the design life does not exceed 2 % of pavement surface), acceptable traffic with a Multicol-AC wearing course is 30,000 Airbus A380 aircraft movements.

Compared to the conventional AAC, a Multicol-AC wearing course would make it possible to multiply by 4 the number of A380 super jumbo movements that the pavement can bear.

In addition to the improved quality and comfort of the pavement, the structural reinforcement provided by Multicol-AC will allow:

- to rapidly adapt existing airport pavement to large aircraft (B777, B747-400, A340, A380) at lower cost,

- or to prolong the service life of the pavement by reducing the costs of maintenance and reinforcement.

The advantage of Multicol is to reinforce the existing structure by limiting or avoiding the removal of existing layers.

<u>Pavement monitoring</u>

The data requested is as follows:

- 4 movements of large aircraft per day

- Type of aircraft (345 tons maximum load), which means a 28 ton load per wheel and 112 tons per landing gear.

The experimental section is currently being monitored, including permanent deformation and surface cracking. Every 3 months.

To date, the pavement has not shown any defects.

Paris Airport Experiment

This experiment is on the holding area (run-up pad) of the "Y11 Way" of the Runway 2 at the Paris airport (the heaviest traffic in Europe).

<u>History</u>

- Basic structure: It is a structure in cement concrete that was completed in 1980:

  400 mm Doweled cement concrete slabs of 7.50 x 7.50 m
  <u>200 mm Lean Concrete</u>
  Subgrade E = 20 MPa

- The first reinforcement was made in 1992: Due to cracks and slabs beats, the existing pavement was reinforced by the following layers:

  60 mm High modulus asphalt concrete
  100 mm High modulus road base asphalt concrete
  <u>20 mm sand bitumen with special anti-reflective cracking properties</u>
  Existing pavement

- The wearing course was repaired on several occasions because of serious deformation and rutting caused by heavy aircraft traffic.

In August 2001, it was decided to carry out experiment with Multicol-AC in order to repair the heavily degraded wearing course (Figure 7).

Figure 7. Existing pavement (before reinforcement).

The goal of this experiment was to validate an asphalt concrete renovation technique and to prove that it is able to fulfill requirements regarding punching, rutting and reflective cracking.

This aircraft traffic is one of most significant of Europe. The average daily traffic totals 50 very large airplanes (weight > 200 tons) with the following average distribution:

Table 4.
Design Aircraft Traffic / Holding Area of Runway 2 of Paris Airport.

Type of Aircraft	Movement per day
Boeing B747-400	30
Airbus A340	10
Boeing B777	6
MD11	3

Reinforcement Solution

Reinforcement consists in substituting the damaged high modulus asphalt concrete wearing course by a 60 mm Multicol-AC.

Verifying Pavement Design

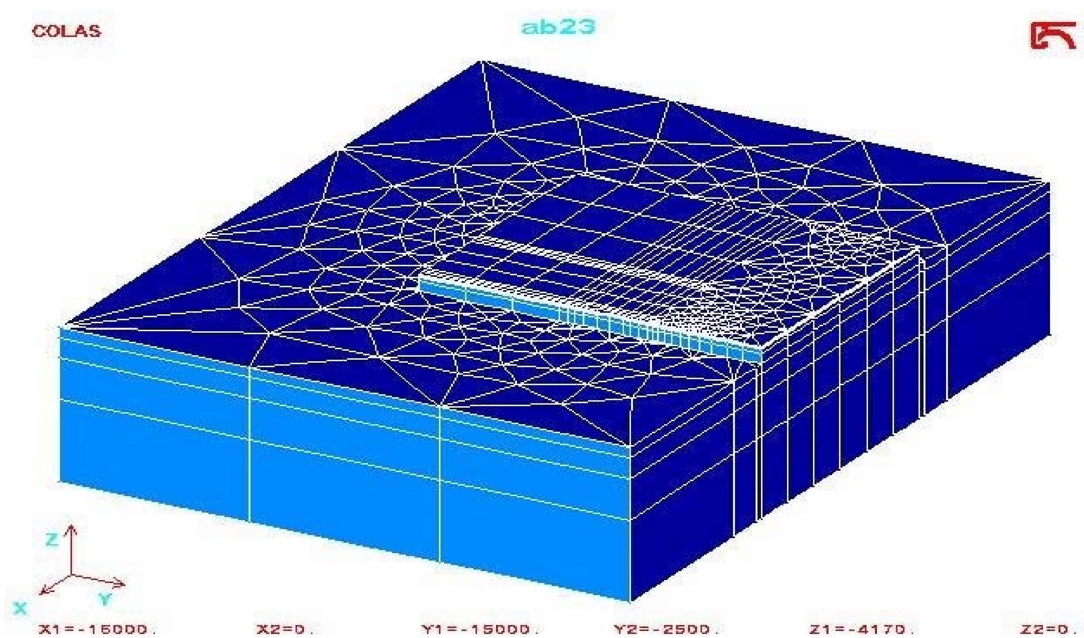

Figure 8. Structure Modeling.

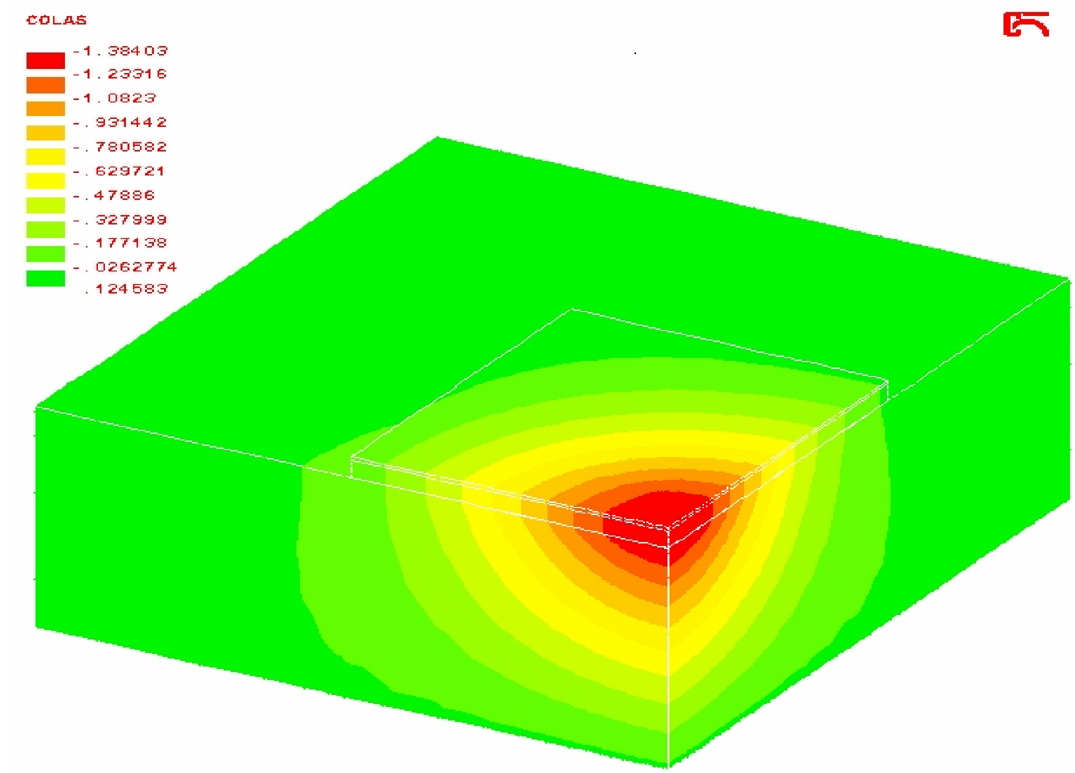

Figure 9. Vertical deformation under Airbus A340-600 gear.

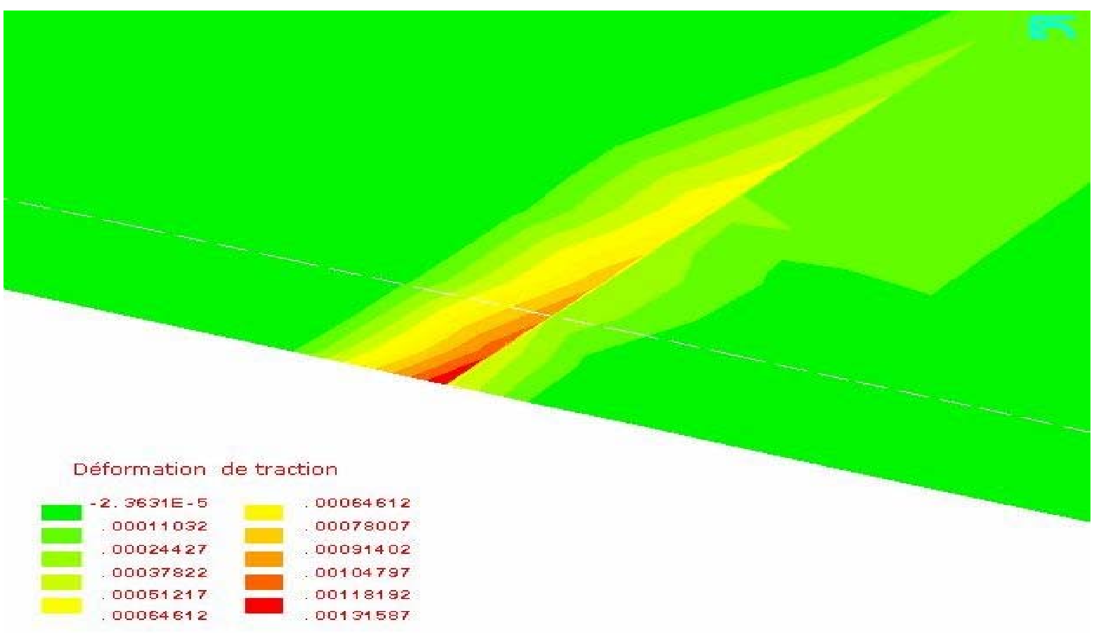

Figure 10. Horizontal tensile strains in HMRBAC under Airbus A340-600 gear.

Pavement monitoring

The experimental section is currently being monitored, including permanent deformation and surface cracking. Every 3 months.

To date, the pavement has not shown any defects.

CONCLUSION

The use of the ELSA design method allows for better modeling of airport pavement structures. This method enjoys a wide range of use and has no restrictions. It allows the design of new pavement as well as the reinforcement of existing pavements, and can also be used to determine the bearing capacity of the airport pavement intended to bear heavier aircraft.

The modeling phase is lengthy, but with relatively negligible costs compared to pavement construction or the risks of improper design.

High performance asphalt concrete is a promising economical solution to adapt the airport pavement to larger jumbo jets (B777, A340-600, A380, etc.).

In addition to improved surface comfort and safety, this new generation of asphalt concrete allows the repair and the reinforcement of existing pavement, either by substitution or by direct overlaying of existing pavement. Thus, thickness and time required for completion are limited.

All materials are recyclable or reusable without restrictions.

Pavement sections are currently being monitored and the validation of the technique still requires a number of seasonal cycles.

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